Research & Development to Improve Measurement Services in Mechanical Quantities

Program Manager: Donald G Eitzen
Total FTE: 5.4
Total Funding: $1,123,000

Goal

To develop advanced measurement methods and instrumentation for mechanical metrology in the areas of mass, force, vibration, shock, acoustics, and ultrasonics to improve NIST capabilities to meet the needs and demands of U.S. industry, government, and the scientific community and to improve public health and welfare.

Program Objectives

FY2000

Develop methods to characterize load cells as a function of environmental factors and type of bridge excitation (i.e., direct current in U.S., alternating current in the rest of the world).

Electromagnetic Testing of Digital Load Cells

To develop the capabilities to test the effects of electromagnetic radiation on the output of digital load cells under realistic force loading conditions.

FY2002

Develop improved ultrasonic modeling and methodology for industrial applications and improved ultrasonic reference block calibration by reducing uncertainty by 1 dB to 2 dB.

Ultrasonic Calibrations Research & Development

Maximize industrial utility of ultrasonic calibration and testing services by maximizing their measurement ranges, minimizing their uncertainties, and minimizing their costs.

Improved Ultrasonic Reference Block Evaluations

Develop improved procedures for ultrasonic reference block evaluation.

FY2003

Develop new ways for performing measurements of hearing aids, micro-electromechanical systems (MEMS)-based microphones, and accelerometers, and communicate results to industrial developers of these new sensors to enable product development.

Improve Measurement Protocol for Hearing Aids

Develop an improved measurement protocol for hearing aids.

Emergency Vehicle Sirens

Develop test procedures and performance requirements for the National Institute of Justice (NIJ), document in a guide for law enforcement agencies, and document in an Society of Automotive Engineers (SAE) publication.

FY2003

Complete all research, development, and validation studies necessary to enable the "super shaker" to be utilized for SP250 calibrations over the frequency range of 10 Hz to 10,000 Hz.

Improve Capabilities of Super Shaker

Design, fabricate, install, and test air-bearing suspension to replace current flexure support for moving element of the Super Shaker.

FY2004

Develop methodology for realizing and disseminating force over new ranges (50 N to 1 nN).

Microforce Realization and Measurements Competence

Examine the lower bound of force metrology, researching the measurement, realization, and representation of forces between 10 nN and 100 mN. The research will develop a novel laboratory and instrumentation to ultimately achieve an uncertainty of parts in 10,000 or better in the representation of nanoscale forces.

FY2004

Complete all research, development and validation studies necessary to enable the replacement of stainless steel mass transfer artifacts by new tungsten-based artifacts and improve measurement capability for mass and density.

Upgrade of Mass Calibration in the 10 g to 500 g Range

Reduce the random uncertainty by factors of 2 to 20 in different parts of the 10 g to 500 g range.

Silicon-Based Density System

Build a new silicon-based, fully automated, solid density system to reduce the measurement uncertainty by at least a factor of 3.

Integration of the Alternating Current (AC) Thermometry Bridge into the Vacuum Mass Balance

Integrate the AC Thermometry Bridge into the clean room's new vacuum and existing balance systems. This will enable integration of temperature values into the automated weighing programs.

FY2007

Complete all research, development, and validation studies necessary to provide for the basis for correlating the current artifact kilogram to the Watt-based electromagnetic realization of the kilogram.

Stability of Mass Standards

Complete design, procurement, and fabrication of system to enable damage-free, in-vacuum transfer of prototype kilogram from mass laboratory vacuum balance to vacuum in watt-balance experiment, study stability of artifacts, and support Watt Experiment.

FY2003

Research and develop the methodology and apparatus for improving microphone calibration uncertainty by implementing a pressure chamber and extending the frequency range to 60,000 Hz.

Research & Development to Improve Acoustical Metrology

Improve acoustic metrology services by improving uncertainty and frequency range to meet new demands of U.S. industry and government.

New Acoustics & Vibration Methods

Develop custom methods for emerging sensors, such as micro-electro-mechanical system (MEMS) microphones and accelerometers, new speakers and hearing aid arrays, and provide consultation to industry on such new devices.

Customer Needs

Through its delivery of improved or new physical measurement services, new realization of the units, new transfer standards, new methods and data, custom tests, and consulting, this program impacts a very broad spectrum of manufacturing industries, commerce, and research. In addition, a broad spectrum of these customers is making new or more severe demands. For example, the mass unit is fundamental for nuclear material accountability, and to drug manufacturers, instrument manufacturers, power companies, weight manufacturers, and state weights and measures laboratories that leverage our impact by performing over 300,000 mass measurements per year. Further, the mass unit is fundamental to the definition of basic and derived Systeme Internationale d'Unites (SI) units in both mechanical and electrical metrology.

New technologies are an important driver of customer needs. In mass, mass comparators have a resolution of better than 1 microgram (better than 1 part per billion) and our customers demand uncertainties compatible with this resolution. However, the stainless steel transfer standards are about 2.5 times larger in volume than the Pt-Ir prototype mass standards. This results in an uncertainty component due to the air buoyancy correction of about 13 micrograms, which argues for a better transfer standard (instability is also a driver). From the history of prototype re-certifications, it appears that the kilogram, the artifact defining the unit, has drifted by about 50 micrograms. This situation is at best unsettling and it affects other units in electrical and mechanical metrology and indicates a need for understanding stability. This drift of the kilogram and other demands from the scientific and metrological community lead to a strong interest in defining a new unchanging fundamental-constant-based redefinition of the unit of mass.

In force and related quantities, there are new customer needs in very small forces (as low as 1 micro-Newton) and potentially in torque and dynamic force. For static force, the NIST deadweight machines provide a realization of force from 44 N to 4.5 MN, with a standard uncertainty of 5 parts per million. This realization is "best-in-the-world" and, for the upper range, unique in the world. However, NIST currently does not have capabilities in small forces, torque, or dynamic force.

In the area of small forces, members of the computer disk drive community, scanned probe microscope instrumentation field, microelectronics field, and biomedical area have expressed interest in the measurement of forces as small as 1 micro-Newton.

Interest in torque measurements has increased both in number and in desired accuracy. Members of the automotive, aerospace, aircraft, and nuclear reactor fields all have a level of interest, often associated with the need to control the pre-strain on fasteners. For example, Germany and Britain are actively working on or have standards and measurement capabilities in torque. It is noted that in some applications, a measurement other than torque, for example, fastener elongation by ultrasonic methods, may be more "direct."

In the area of dynamic force, the automotive community and others have expressed interest. Crash test measurements are one motivation behind this interest. Other national laboratories expressed increased interest in this area too. A joint project has been defined in Japan between the national laboratory and a major automobile producer. In this case the measurement challenge of dynamic force is being approached by way of transient acceleration measurement.

In the areas of acoustics and vibration, parallel drivers are at work. Constantly more sophisticated hearing aids (and arrays) demand development of more complex testing methods and signal input and processing. Micro-electromechanical systems (MEMS) technology has led to much smaller microphones, which will require development and

analysis of new smaller microphone coupler techniques. More sophisticated loudspeakers push toward offering designers and manufacturers new measurement capabilities. European Union (EU) directives on electromagnetic interference (EMI) and implementation by other national laboratories are forcing a stronger demand for capabilities at NIST for EMI measurements on acoustic instruments and digital load cells. New pressures arise from compliance with noise and vibration standards and directives for jet engines, automobiles, and machine tools. Industries such as aerospace rely heavily on absolute vibration measurements that drive increased capabilities. Expanded use of accelerometers, including but beyond air bags, also lead to demands.

An ever-increasing demand for process monitoring inspection and structural inspection (e.g., aging aircraft and chemical storage structures) lead to a need for new measurement methods and services. Medical applications of ultrasound, such as fetal scans, are another strong driver of measurement research.

Two related drivers also play a role. 1) The Director of NIST has demanded that our measurement capabilities be among the best in the world. 2) International comparisons of all quantities associated with this program are underway or are being planned for the near future. These needs significantly impact our activities. For example, a current international comparison on mass was one motivator for a recent upgrade in capabilities in mass for the 2 kg to 10 kg range, a planned improvement in the 100 g to 500 g range, and improvements of the super shaker.

Additional information regarding industry segments served and other motivators can be found in the MEL Program "Measurement Services for Mechanical Quantities."

Technical Approach

To achieve its objectives, this program will continue to perform research and development that leads to new methodologies for improved measurement services, methods for new quantities or expanded ranges, more fundamental realizations of the unit, and new measurement methods and data in support of industrial product development. It will also acquire additional research tools and will improve research facilities. The effort is largely measurement-based, but includes important theoretical, analytical, and computational aspects. Many source contributed to the input for these objectives including: active feedback from current customers, inquiries from prospective customers, close interactions with other National Measurement Institutes (NMIs), professional and standards meetings, laboratory visits, and knowledge of the larger components of error budgets. This often leads to the definition of an objective to establish a new or improved measurement service or to undertake a measurement-related custom project for a customer. After defining an objective, analysis is performed to create one or more concepts that might achieve the objective; frequently this involves extensive interaction with internal or external experts and discussions with other NMIs about prospective methods and lessons learned. This is followed by a detailed analysis of a more concrete process that leads to constraints and error expectations and an error budget. A prototype is often built after performance goals have been defined. The decision to build internal or external involves many factors, including expertise, resources, and schedules. The prototype is expected to meet or exceed performance criteria, but in most cases, several iterations of measurements, analysis, and modifications are required. The system and methodology are tested rigorously for an extended period of time, sometimes lasting as long as several

years. The measurement may then be offered as a special test, and with sufficient confidence in uncertainty and documentation, as a calibration service.

By way of an example, sensor manufacturers and system integrators identified the need for more accurate accelerometer calibration. NIST, the Italian national laboratory, and a consultant with decades of experience in the design and construction of shakers defined the concept of the super shaker. Performance criteria were developed by NIST. It has been shown that at a limited range of measurement frequencies, the super shaker has lower motional waveform distortion and lower cross axis motion than specified and has a key attribute of allowing measurements by two totally independent methods. Plans are currently underway to improve the frequency range of measurements by replacing the flexure support (which has "low" resonance) with an air bearing support and increasing accuracy by replacing the prototype interferometer with a multiple-arm interferometer. This may lead to, among many other things, more accurate firing of automobile air bags.

Standards Participation

- Acceleration Standards: See the respective column for Acceleration in the table provided in the MEL Program: "National, Regional, and International Standards and Comparisons"
- Acoustics Standards: See the respective column for Acoustics in the table provided in the MEL Program: "National, Regional, and International Standards and Comparisons"
- Force Standards: See the respective column for Force in the table provided in the MEL Program: "National, Regional, and International Standards and Comparisons"
- Mass Standards: See the respective column for Mass in the table provided in the MEL Program: "National, Regional, and International Standards and Comparisons"
- Ultrasonics Standards: See the respective column for Ultrasonics in the table provided in the MEL Program: "National, Regional, and International Standards and Comparisons"

Accomplishments

- September FY1999 Completed additional custom tests and consulting on the Army's Family of Loudspeakers in the large anechoic chamber.
- September FY1999 Completed measurements on emergency vehicle sirens for the Department of Justice and the NIST Electronics and Electrical Engineering Laboratory and wrote a guide for selection.
- September FY1999 Completed improved measurement protocol and signal processing for new hearing aids that led to better patient-hearing aid match for veterans, and better data for hearing aid developers and consumers.
- September FY1999 Provided artifact and mechanical support for NIST's Electronics and Electrical Engineering Laboratory's (EEEL) Watt experiment in quest of a more fundamental definition of the mass unit, a goal demanded by scientists worldwide.
- September FY1999 Improved suspension of Super Shaker moving element for reduced cross-axis motion.
- September FY1999 Completed design and specification of system for controlled-pressure microphone calibration.
- September FY1999 Developed special test services of International Electrotechnical Commission (IEC) LS2aP microphones and for using them to tests calibrators from 125 Hz to 2 kHz.

- September FY1999 Evaluated ultrasonic sensors and waveforms to optimize monitoring of cutting and ceramic grinding that will lead greatly to improved performance.
- September FY1999 Completed the planning of the statistical analyses of ultrasonic reference block calibration system performance.
- September FY1999 Evaluated specific piezoelectric ceramics transducers as potential replacements for the quartz standard source for the American Society for Testing and Materials (ASTM) standard.
- August FY1999 Designed a temperature probe array for monitoring the kilogram comparator.
- August FY1999 Demonstrated vibration calibration capabilities well below 0.5 % uncertainty at selected frequencies.
- June FY1999 Completed a study (and paper published in Organization Internationale de Metrologie Legale (OIML) Bulletin) on creep and creep recovery of load cells. This will have a great impact on normalization of standards documents and greatly improve market access by U.S. scale manufacturers.
- May FY1999 Completed a study of measurements of super shaker performance by two independent methods showing remarkable agreement; published a paper on the results in Metrologia (invited).
- April FY1999 Completed invited paper on primary calibration methods in acoustics for a Special Issue of Metrologia.
- February FY1999 Completed initial surface profiles and micrographs of mass Pt-Ir prototypes K4 and K79, the first surface pictures of any prototype in the world.
- December FY1999 With the Fabrication Technology Division, completed the initial concept of air bearing support for the super shaker moving element.
- September FY1998 Completed an upgrade of mass calibration in the 2 kg to 10 kg range.
- January FY1998 Completed the installation, configuration, and inauguration of the new Mass Clean Room Facility.
- December FY1997 Analyzed and measured microphone acoustic center correction which addresses large disagreement in recent European comparison; published results in Journal of the Acoustical Society of America (JASA).